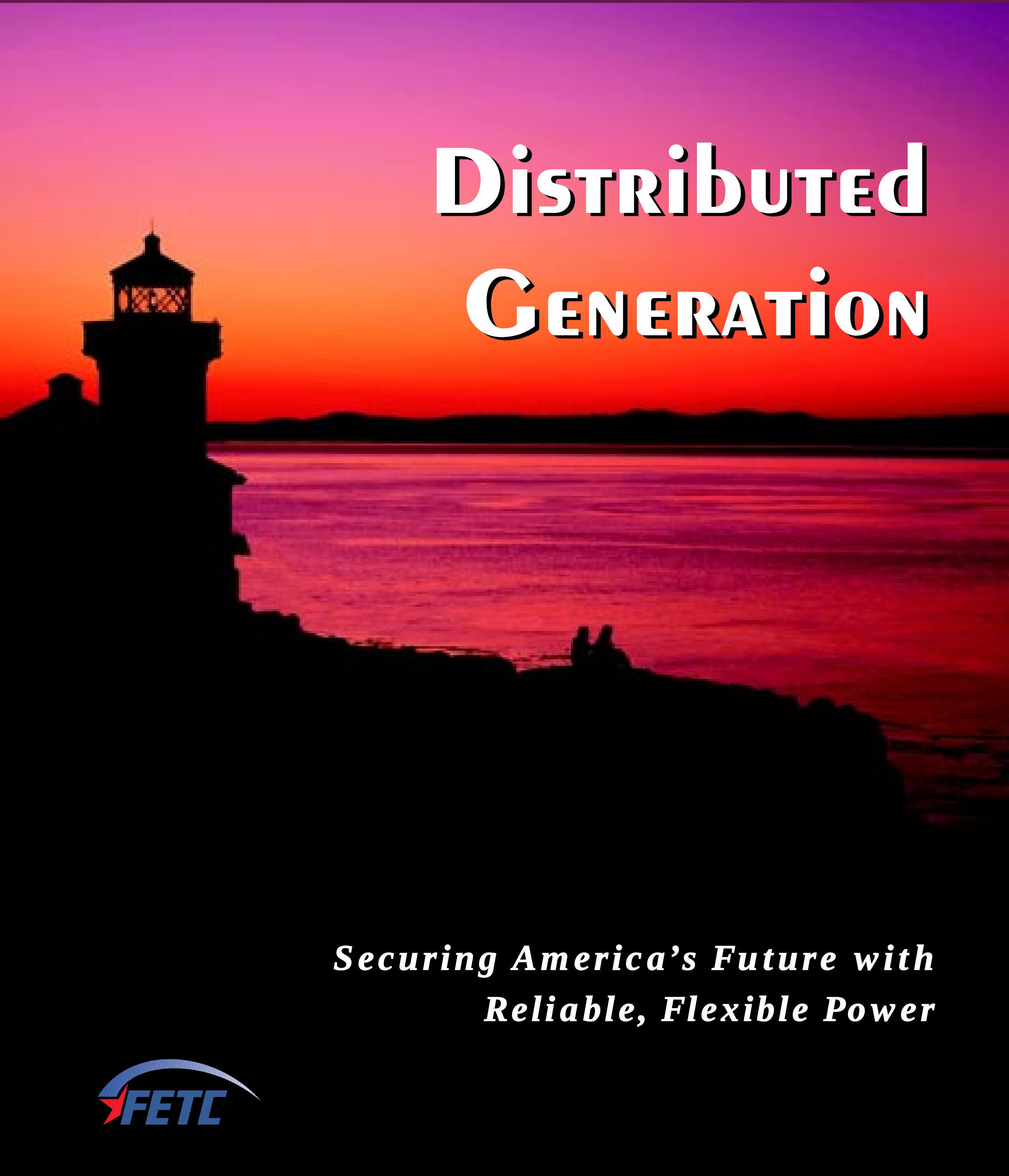
U.S. Department of Energy • Office of Fossil Energy
Federal Energy Technology Center



Distributed Generation

Securing America's Future with Reliable, Flexible Power

FETC

The Federal Energy Technology Center (FETC), a field office of the Department of Energy's Office of Fossil Energy, is a proven leader in forging research and development partnerships with industry in the field of fossil fuel-based power generation. FETC manages over 700 energy and environmental research, development, and demonstration projects and conducts cooperative in-house research on clean and efficient use our nation's fossil energy resources.

Among FETC's responsibilities is implementation of a program in distributed power generation—a revolutionary approach that is changing the way power systems are applied. Through this effort, a portfolio of small, modular stationary power systems are making it possible to readily install power at customer sites in lieu of capital-intensive central power generation capacity additions and transmission and distribution line upgrades. These distributed generation systems avoid the usual siting problems by being small, compact, and extremely clean. Customer satisfaction derives from the characteristically high efficiency and reliable service.

Like a lighthouse, the emerging distributed generation systems are guiding the way toward addressing growing energy and environmental concerns, and leading to more efficient, clean energy use and energy independence.

DISTRIBUTED GENERATION

Energy Systems for the New Millennium

A confluence of utility restructuring, technology evolution, public environmental policy, and an expanding electricity market are providing the impetus for distributed generation to become an important energy option in the new millennium. Utility restructuring opens energy markets, allowing the customer to choose the energy provider, method of delivery, and attendant services. The market forces favor small, modular power technologies that can be installed quickly in response to market signals. This restructuring comes at a time when:

- Demand for electricity is escalating domestically and internationally;
- Impressive gains have been made in the cost and performance of small, modular distributed generation technologies;
- Regional and global environmental concerns have placed a premium on efficiency and environmental performance; and
- Concerns have grown regarding the reliability and quality of electric power.

Emerging on the scene is a portfolio of small, modular gas-fueled power systems that have the potential to revolutionize the power market. Their size and extremely clean performance allow them to be sited at or near customer sites in what are called distributed generation applications.

These distributed generation systems also afford fuel flexibility by operating on natural gas, propane, or fuel gas derived from any hydrocarbon, including coal, biomass, and wastes from refineries, municipalities, and the forestry and agricultural industries. Technologies such as gas turbines and reciprocating engines are already making a contribution and they have more to offer through focused development efforts. Fuel cells are beginning to enter the market, but require additional research and development to realize widespread deployment. Lastly, fuel cell/turbine hybrid systems and 21st century fuel cells, currently in the embryonic stage, offer even greater potential.

While addressing distributed generation potential in general, this document focuses on stationary energy gas-based distributed generation technologies and the Federal Energy Technology Center's efforts to bring them into fruition.

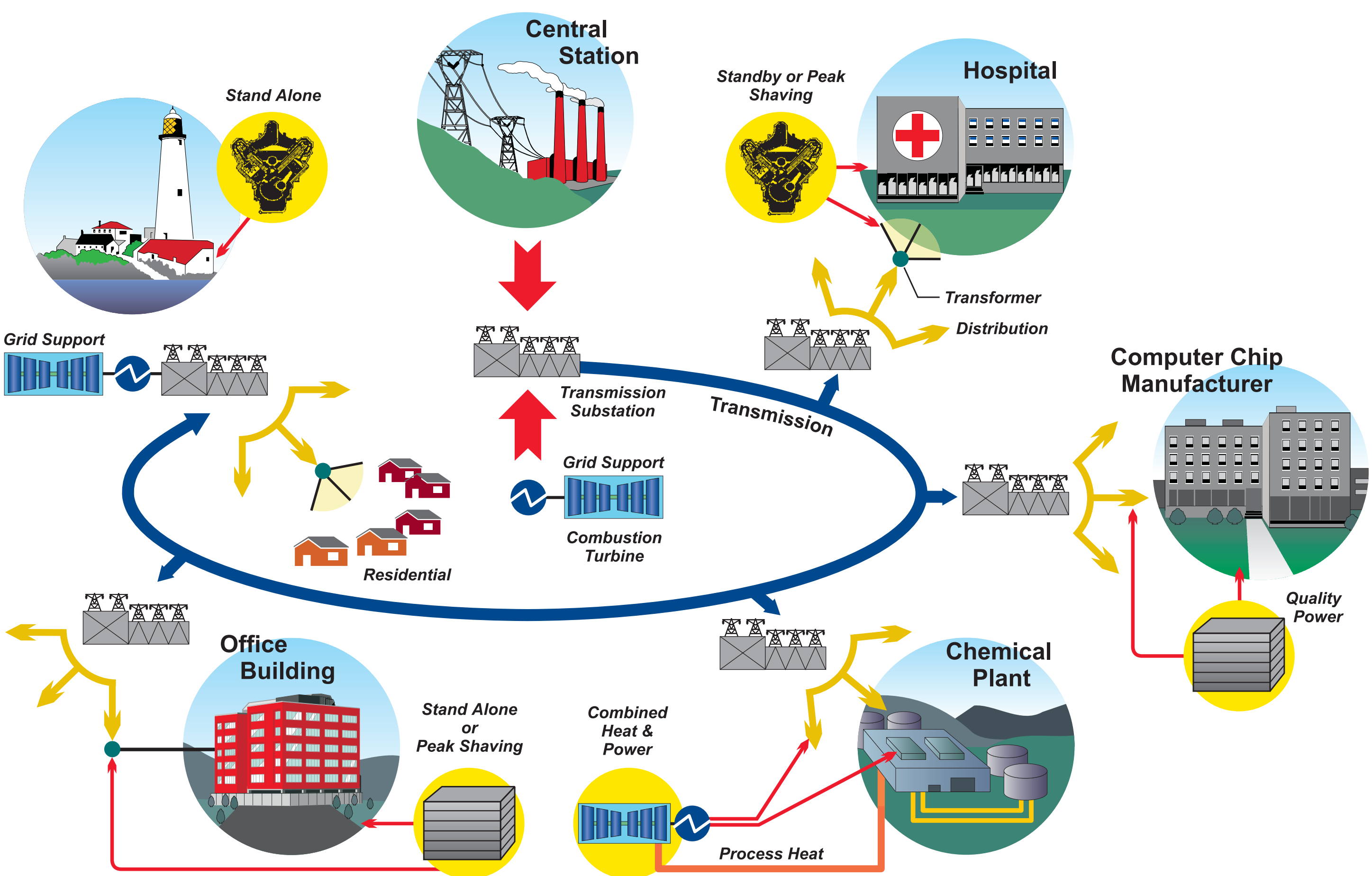
Distributed Generation—

What is Distributed Generation?

Distributed generation strategically applies relatively small generating units (typically less than 30 MWe) at or near consumer sites to meet specific customer needs, to support economic operation of the existing power distribution grid, or both. Reliability of service and power quality are enhanced by proximity to the customer, and efficiency is improved in on-site applications by using the heat from power generation.

While central power systems remain critical to the nation's energy supply, their flexibility to adjust to changing energy needs is limited. Central power is composed of large capital-intensive plants and a transmission and distribution (T&D) grid to disperse electricity. Both require significant investments of time and money to increase capacity. Distributed generation complements central power by (1) providing a relatively low capital cost response to incremental increases in power demand, (2) avoiding T&D capacity upgrades by locating power where it is most needed, and (3) having the flexibility to put power back into the grid at user sites.

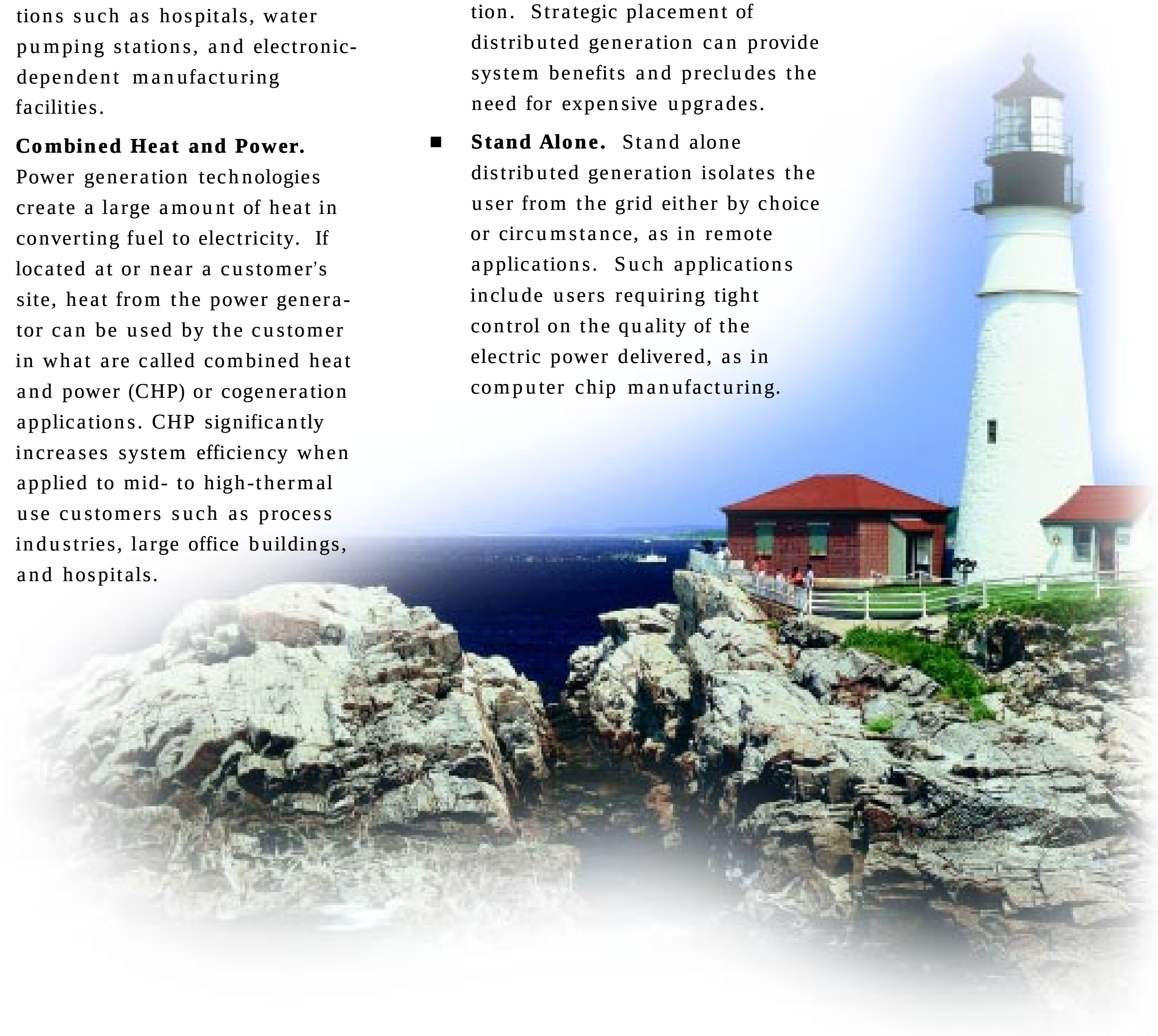
Significant technological advances through decades of intensive research have yielded major improvements in the economic, operational, and environmental performance of small, modular gas-fueled power generation options. These distributed generation systems, capable of operating on a broad range of gas fuels, offer clean, efficient, reliable, and flexible on-site power alternatives. This emerging portfolio of distributed generation options being offered by energy service companies and independent power producers is changing the way customers view energy.



Applications

There are a number of basic applications, outlined below, that represent typical patterns of services and benefits derived from distributed generation.

- **Standby Power.** Standby power is used for customers that cannot tolerate interruption of service for either public health and safety reasons, or where outage costs are unacceptably high. Since most outages occur as a result of storm or accident related T&D system breakdown, on–site standby generators are installed at locations such as hospitals, water pumping stations, and electronic-dependent manufacturing facilities.
- **Combined Heat and Power.** Power generation technologies create a large amount of heat in converting fuel to electricity. If located at or near a customer's site, heat from the power generator can be used by the customer in what are called combined heat and power (CHP) or cogeneration applications. CHP significantly increases system efficiency when applied to mid- to high-thermal use customers such as process industries, large office buildings, and hospitals.
- **Peak Shaving.** Power costs fluctuate hour by hour depending upon demand and generation availability. These hourly variations are converted into seasonal and daily time-of-use rate categories such as on-peak, off-peak, or shoulder rates. Customer use of distributed generation during relatively high-cost on-peak periods is called peak shaving. Peak shaving benefits the energy supplier as well, when energy costs approach energy prices.
- **Grid Support.** The power grid is an integrated network of generation, high voltage transmission, substations, and local distribution. Strategic placement of distributed generation can provide system benefits and precludes the need for expensive upgrades.
- **Stand Alone.** Stand alone distributed generation isolates the user from the grid either by choice or circumstance, as in remote applications. Such applications include users requiring tight control on the quality of the electric power delivered, as in computer chip manufacturing.



BENEFITS

Customer Benefits

- Ensures reliability of energy supply, increasingly critical to business and industry in general, and essential to some where interruption of service is unacceptable economically or where health and safety is impacted;
- Provides the right energy solution at the right location;
- Provides the power quality needed in many industrial applications dependent upon sensitive electronic instrumentation and controls;
- Offers efficiency gains for on-site applications by avoiding line losses, and using both electricity and the heat produced in power generation for processes or heating and air conditioning;
- Enables savings on electricity rates by self generating during high-cost peak power periods and adopting relatively low-cost interruptible power rates;
- Provides a stand-alone power option for areas where transmission and distribution infrastructure does not exist or is too expensive to build;
- Allows power to be delivered in environmentally sensitive and pristine areas by having characteristically high efficiency and near-zero pollutant emissions;
- Affords customers a choice in satisfying their particular energy needs; and
- Provides siting flexibility by virtue of the small size, superior environmental performance, and fuel flexibility.

Supplier Benefits

- Limits capital exposure and risk because of the size, siting flexibility, and rapid installation time afforded by the small, modularly constructed, environmentally friendly, and fuel flexible systems;
- Avoids unnecessary capital expenditure by closely matching capacity increases to growth in demand;
- Avoids major investments in transmission and distribution system upgrades by siting new generation near the customer;
- Offers a relatively low-cost entry point into a competitive market; and
- Opens markets in remote areas without transmission and distribution systems, and areas without power because of environmental concerns.

National Benefits

- Reduces greenhouse gas emissions through efficiency gains and potential renewable resource use;
- Responds to increasing energy demands and pollutant emission concerns while providing low-cost, reliable energy essential to maintaining competitiveness in the world market;
- Positions the United States to export distributed generation in a rapidly growing world energy market, the largest portion of which is devoid of a transmission and distribution grid;
- Establishes a new industry worth billions of dollars in sales and hundreds of thousands of jobs; and
- Enhances productivity through improved reliability and quality of power delivered, valued at billions of dollars per year.

The Opportunity

The importance of distributed generation is reflected in the size of the estimated market. Domestically, new demand combined with plant retirements is projected to require as much as 1.7 trillion kilowatt-hours of additional electric power by 2020, almost twice the growth of the last 20 years. Over the next decade, the domestic distributed generation market, in terms of installed capacity to meet the demand, is estimated to be 5–6 gigawatts per year. Worldwide forecasts show electricity consumption increasing from 12 trillion kilowatt hours in 1996 to 22 trillion kilowatt hours in 2020, largely due to growth in developing countries without nationwide power grids. The projected distributed generation capacity increase associated with the global market is conservatively estimated at 20 gigawatts per year over the next decade.

The projected surge in the distributed generation market is attributable to a number of factors. Under utility restructuring, energy suppliers, not the customer, must shoulder the financial risk of the capital investments associated with capacity additions. This favors less capital-intensive projects and shorter construction schedules. Also, while opening up the energy market, utility restructuring places pressure on reserve margins, as energy suppliers increase capacity factors on existing plants to meet growing demand rather than install new capacity. This also increases the probability of forced outages. As a result, customer concerns over reliability have escalated, particularly those in the manufacturing industry.

With the increased use of sensitive electronic components, the need for reliable, high-quality power supplies is paramount for most industries. The cost of power outages, or poor quality power, can be ruinous to industries with continuous processing and pinpoint-quality specifications. Studies indicate that nationwide, power fluctuations cause annual losses of $12–26 billion.

As the power market opens up, the pressure for enhanced environmental performance increases. In many regions in the U.S. there is near-zero tolerance for additional pollutant emissions as the regions strive to bring existing capacity into compliance. Public policy, reflecting concerns over global climate change, is providing incentives for capacity additions that offer high efficiency and use of renewables.

Overseas, the utility sector is undergoing change as well, with market forces displacing government controls and public pressure forcing more stringent environmental standards. Electricity demand worldwide is forecasted to nearly double. Moreover, there is an increasing effort to bring commercial power to an estimated 2 billion people in rural areas currently without access to a power grid.

Robotic fabrication, as shown here, is becoming commonplace in the manufacturing industry and is mandating high-quality power for the associated electronic components

THE CHALLENGE

Although growing, distributed generation is still in its infancy. Ultimately, the market will be shaped by crucial product development and economic, institutional, and regulatory issues.

Market penetration will depend on how well manufacturers of distributed generation systems do in meeting product pricing and performance targets. Many of the more promising technologies have not yet achieved market entry pricing or risk levels, while others simply have not reached their market potential.

Customers—utilities, energy service companies, and end users—have yet to define and quantify distributed generation attributes such as transmission and distribution upgrade cost avoidance, improved grid stability, or enhanced power reliability.

A major institutional issue, regarding customer interconnection with the distribution grid, currently stands in the way of distributed generation. Utility specifications for connection with the grid are complex and lack clarity and consistency. The results are high costs and project delays, or termination. Clearly, interconnect requirements are needed for safety, reliability, and power quality purposes. This strongly suggests the development of transparent national interconnect standards. Also needing to be addressed are the historical use charges, back-up charges, insurance charges, and other utility fees associated with those choosing to self-generate while remaining connected to the grid. Moreover, there is the matter of high liability insurance coverage for mis-operations of the distributed generator, needed to protect the utility.

Regulatory issues arise as well. For example, unless changes are made, distributed generation units may not get credit for avoided pollutant emissions. These emission credits are normally dealt with during the utility resource planing process, not during operation.

To realize the potential of distributed generation, the technical, economic, institutional, and regulatory issues must be dealt with effectively. This task will require cooperation between the public and private sectors. In doing so, a new industry can emerge benefitting the economy through jobs and revenues. FETC's role is to foster the partnerships, cost- and risk-share technology development, and seek to resolve issues through policy development.

THE PROGRAM

Goal

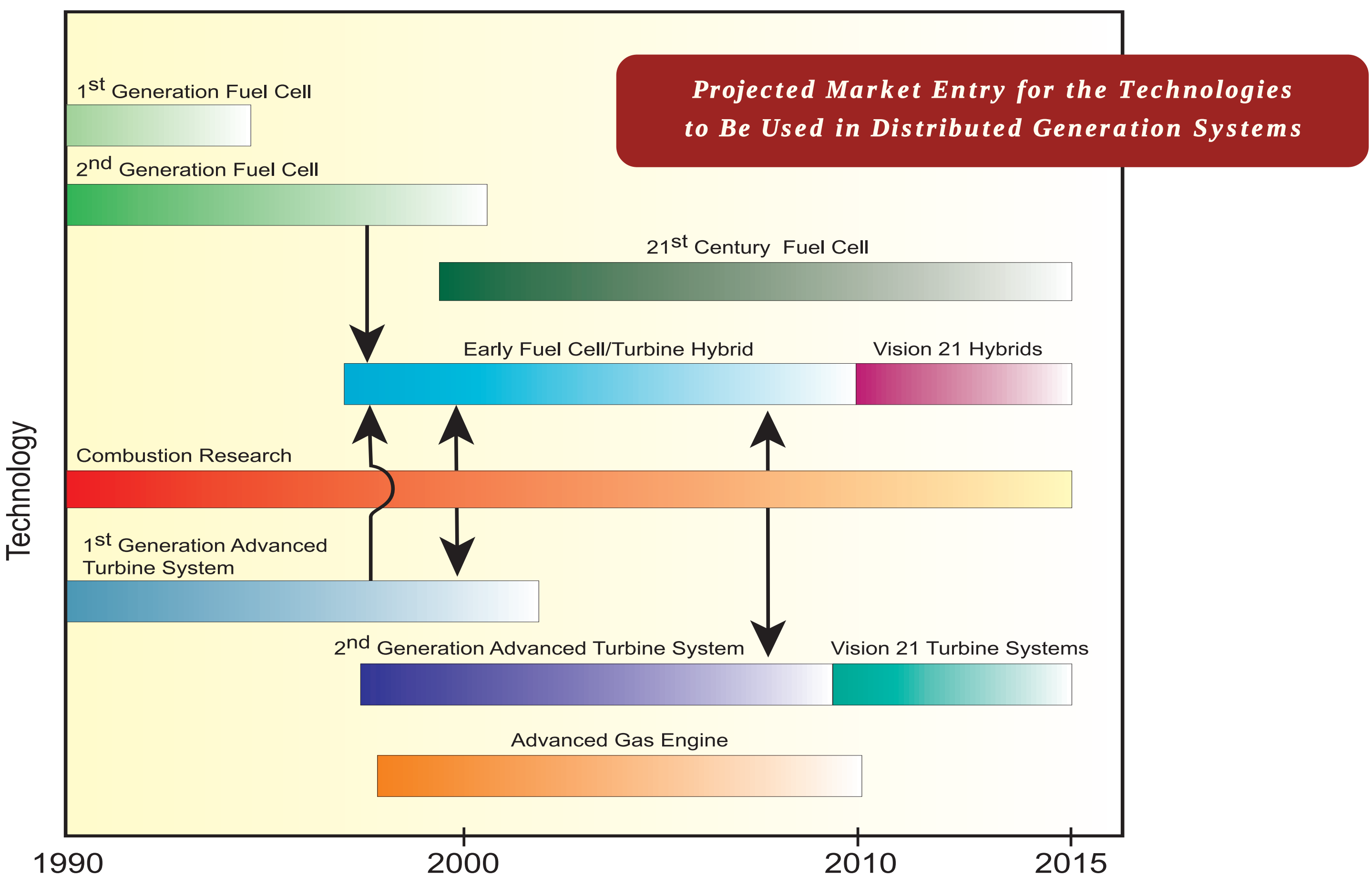
The Department of Energy is fostering the establishment of a strong national distributed generation capability through a program supporting:

- Research, development, and demonstration to optimize the cost and performance and to accelerate the readiness of a portfolio of advance gas-fueled distributed generation systems for both domestic and foreign markets; and
- Policy development necessary to remove barriers to widespread distributed generation deployment.

Strategy

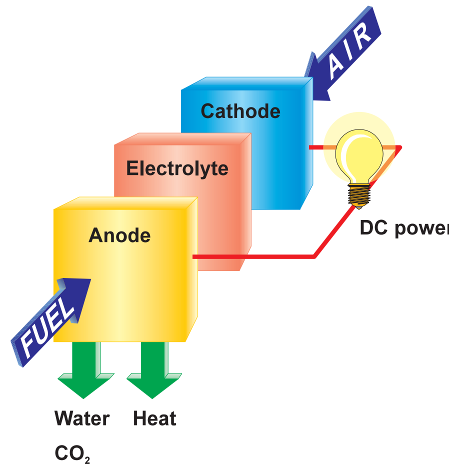
The Department is carrying out the Program by:

- Working in partnership with other federal agencies, state governments, technology suppliers, industry research organizations, academia, power generators, energy service companies, and end users;
- Sharing in the cost and risk of technology development;
- Providing forums for discussion of issues and Program content;
- Ensuring that customers and stakeholders have needed Program information; and
- Nurturing partnerships that support Program goals.



How Fuel Cells Work

Fuel cells work without combustion and its environmental side effects. Power is produced electrochemically by passing a hydrogen-rich fuel over an anode and air over a cathode and separating the two by an electrolyte. In producing electricity, the only by-products are heat, water, and carbon dioxide (CO_2). Hydrogen fuel can come from a variety of hydrocarbon resources by subjecting them to steam under pressure (called reforming or gasification). The electrolyte, which induces the fuel cell's electrochemical reactions, can be composed of liquid or solid media. The media used differentiates the type of fuel cell.



A Revolutionary Device Enters the Market

A cooperative government/industry effort has resulted in successful commercialization of a first generation of fuel cells using a phosphoric acid electrolyte. Turnkey 200-kW phosphoric acid fuel cell (PAFC) plants have been installed at more than 165 sites around the world. PAFC systems operate at about 200 °C (400 °F) with electrical efficiencies ranging from 40–45 percent on a lower heating value (LHV) basis.

Another effort is helping to bring proton exchange membrane (PEM) fuel cells into commercialization by supporting their introduction into military applications, as well as other specialized applications demanded by government agencies. An example is the deployment of a 7-kW PEM fuel cell at an historic Coast Guard lighthouse. Following the evaluation of this technology, the Coast Guard will deploy these fuel cells at other related "Aides to Navigation" applications.

The direct electrochemical reaction, in lieu of moving parts to produce electricity, has inherent efficiency advantages. Efficiency can be enhanced by using the high energy heat derived from the fuel cell reactions either in combined heat and power (CHP) or combined-cycle applications (generating steam for additional electric power). The CO_2 is in concentrated form, which facilitates capture for recycling or sequestration. An absence of moving parts results in very low noise levels. Stacking cells to obtain a usable voltage and power output allows fuel cells to be built to match specific power needs, and the modularity makes capital cost relatively insensitive to scale.

Fuel Cells—Future Generations

Second generation fuel cells are under development to provide both higher fuel-to-electricity efficiencies and temperatures. The technologies include the molten carbonate fuel cell (MCFC) and the solid oxide fuel cell (SOFC). The high temperatures (650 °C for MCFCs and 1,000 °C for SOFCs) enable internal reforming of fuels, and provide high quality heat for CHP and combined-cycle applications. Moreover, these units either tolerate or use reformed fuel constituents such as carbon monoxide, which represents a poison to PAFCs and PEMs. The heat developed in producing electricity also makes MCFCs and SOFCs ideal candidates for integration with gas turbines. Both have the potential to reach fuel-to-electricity efficiencies of 60 percent LHV and 85 percent LHV in CHP and combined-cycle applications.

These second generation systems are currently being demonstrated, with market entry for natural gas-based systems planned for 2002. Demonstration objectives include reducing capital costs to $1,000–1,500/kW. Subsequent to market entry, capital costs are expected to decline as manufacturing capacity and capability increase. Follow-on testing will address expanding the fuel options by testing other reformed fuels and associated cleanup systems.

Parallel research and development into new ceramic materials and manufacturing techniques is ongoing. It explores means to enhance performance and lower costs in support of both MCFC and SOFC development, as well as future 21st Century Fuel Cells that can be manufactured at far lower cost and reach efficiencies of 80 percent LHV. These potentially very low-cost fuel cells promise deeper and wider market penetration.

Energy Research Corporation's first commercial prototype 250-kW MCFC full-size stack demonstration unit

FETC has established a fuel cell test and evaluation facility to simulate operating cycles typical of military and other specialty applications for fuel cells in the 20–5,000 watt range. The objective is to explore, through joint government-industry-academia partnerships, new ways to leverage the unique performance characteristics of fuel cells. The facility provides the fuel, thermal management, humidification, load simulation, and performance measurement instrumentation necessary to fully evaluate fuel cell systems.

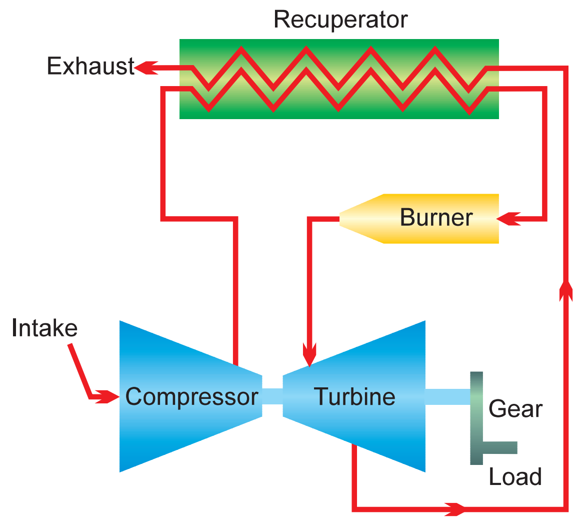
FETC fuel cell test and evaluation facility

TECHNOLOGY THRUSTS—Gas Turbines

A gas turbine produces a high-temperature, high pressure gas working fluid through combustion, to induce shaft rotation by impingement of the gas upon a series of specially designed blades. The shaft rotation drives an electric generator and a compressor for the air used by the gas turbine. Many turbines also use a heat exchanger called a recuperator to impart turbine exhaust heat into the combustor's air/fuel mixture. As for capacity, recently emerging microturbines, evolved from automotive turbochargers, are about to enter the market with outputs as low as 25 kW. Next generation utility-scale turbines are rated at nearly 400 MW in combined-cycle applications.

Gas turbines produce high quality heat that can be used to generate steam for CHP and combined-cycle applications, significantly enhancing efficiency. They accommodate a variety of gases including those derived from gasification of coal, biomass, and hydrocarbon wastes. However, pollutant emissions, primarily nitrogen oxides, are a concern particularly as turbine inlet temperatures are increased to improve efficiency.

To address emission concerns, FETC has recently built a Low Emissions Combustor Test and Research (LECTR) facility. The LECTR offers the latest diagnostic capabilities and high temperature, pressure, and mass flows, which makes it suited to evaluate advanced combustor concepts up to 10 million Btu per hour. FETC plans to integrate a Syngas Generator with the LECTR to enable evaluation of combustion issues associated with integrating gas turbines with advanced power systems, such as integrated gasification combined-cycle and pressurized fluidized-bed combustion.



Typical Gas Turbine

The Office of Fossil Energy's Federal Energy Technology Center and Office of Energy Efficiency and Renewable Energy's Office of Industrial Technologies share responsibility for the Advanced Turbine Systems Program with industrial partners. The program combines the resources of the government, major turbine manufacturers, suppliers, and universities. Gas turbines being developed under the Program are simple-cycle industrial gas turbines for distributed generation, industrial, and cogeneration markets and gas turbine combined-cycle systems for large baseload, central-station electric power generation markets. Expectations are to meet or exceed 60-percent system efficiencies in the utility market, and to increase efficiencies of industrial turbines by 15 percent.

In the near-term, gas turbines with efficiencies of 40–43 percent will be available as a result of two ATS projects. Under the ATS Program, the Allison Engine Company is taking the approach of increasing the inlet temperature to 2,400 °F, increasing the pressure ratio to 30:1, and using staged lean premix fuel injection and catalytic combustion.

Plans are to introduce these features in an existing product line. Solar Turbines, Inc. is using a modest inlet temperature of 2,200 °F and pressure ratio of 9:1, and incorporating a high efficiency recuperator. These features are to be incorporated in the 4.2-MWe Solar Mercury™ 50 and introduced into the market in 2000.

The ATS Program includes two supporting activities. One addresses critical materials and manufacturing issues, with the objective of hastening the incorporation of new materials and components in gas turbines. Work includes development of thermal barrier coatings and advanced casting techniques for single crystal turbine components, and is being carried out by industry with assistance from national laboratories and universities. The other supporting activity, the Advanced Gas Turbine Systems Research (AGTSR) Program, is an effort to establish a scientific foundation for a 21st century gas turbine. The South Carolina Institute for Energy Studies is coordinating the AGTSR Program, a consortium of more than 97 universities in 37 states formed to advance the fundamental knowledge base in gas turbines requisite to continued improvement.

As for future activities, the advanced turbine systems will become the platforms for the fuel cell/turbine hybrids. And the advanced high-temperature materials and supporting processes emerging from successful research will be integrated into ATS components and subsystems over time to enhance efficiency and performance.

System Integration Yields Synergy

Efforts have also begun to develop a system that integrates a fuel cell with a gas turbine. Hybrid fuel cell/gas turbine technology for stationary power generation offers the potential to achieve efficiencies in excess of 80 percent, nitrogen oxides and carbon monoxide emissions less than 2 parts per million (ppm), and costs 25 percent below a comparably sized fuel cell.

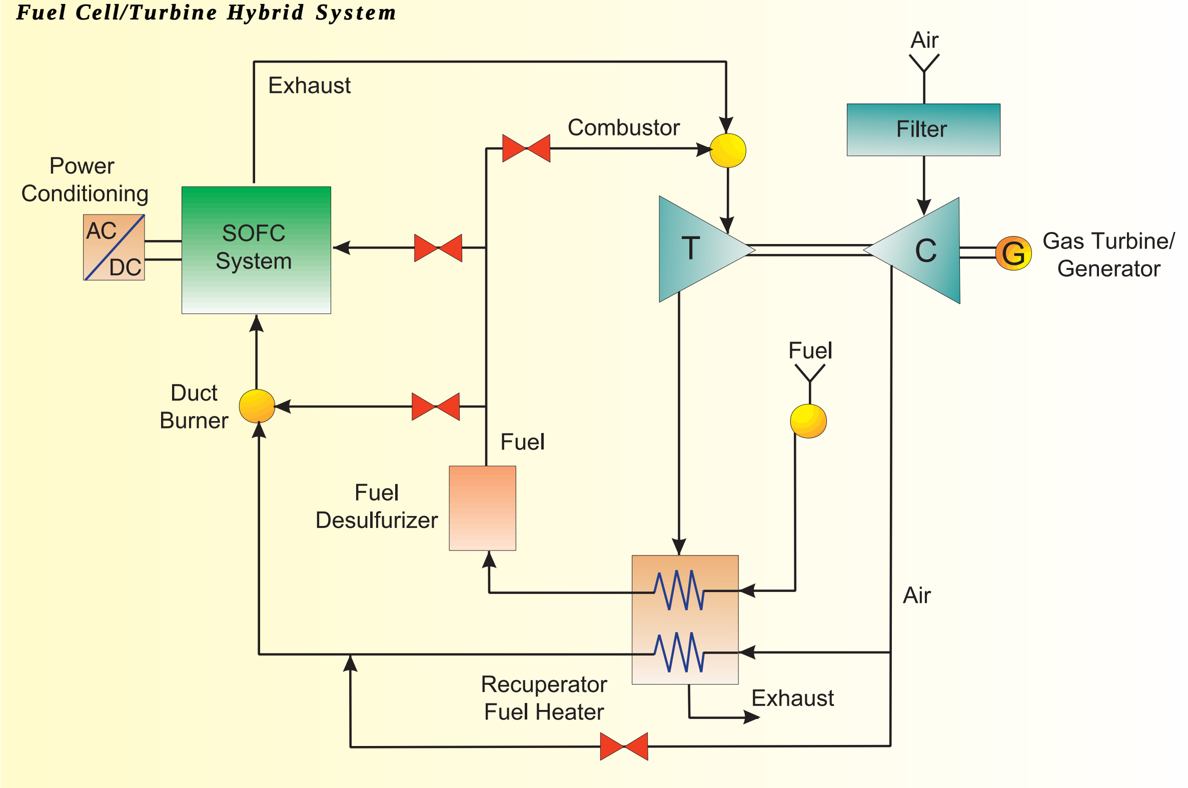
The synergy realized by fuel cell/turbine hybrids derives primarily from using the rejected thermal energy and combustion of residual fuel from a high-temperature fuel cell to drive the gas turbine. Use of a recuperator contributes to thermal efficiency by transferring heat from the gas turbine exhaust to the fuel and air used in the system.

FETC is also engaged in exploratory research on fuel cell/turbine hybrids in partnership with the National Fuel Cell Research Center at the University of California at Irvine. The experimental work involves evaluation of a 75-kW turbine operating in combination with a simulated fuel cell. The particular focus is on dynamic operating conditions (start-up, shutdown, load following, and upsets) and the associated controls. The objective is to establish: key operating parameters and their interrelationships, a range of safe operating conditions, and a database and dynamic modeling tools to support further development.

FETC also supports hybrid systems development in its Low-Btu Combustion Studies Facility. High-temperature fuel cell anode gases can be simulated for combustor design studies. The fully instrumented facility is made available for cooperative research under Cooperative Research and Development Agreements (CRADAs), which are designed to protect participants' intellectual property.

Five teams of fuel cell and turbine manufacturers are currently conducting conceptual feasibility studies on fuel cell/turbine hybrids. The goal is to develop hybrid systems with efficiencies greater than 70 percent for market entry by 2010. More advanced hybrids configured with 21st century fuel cells could offer 80 percent efficiency by 2015.

Fuel Cell/Turbine Hybrid System



TECHNOLOGY THRUSTS—Reciprocating Engines

Reciprocating engines, or piston-driven internal combustion engines, are a widespread and well-known technology. These engines offer low capital cost, easy start-up, proven reliability, good load-following characteristics, and heat recovery potential. Incorporation of exhaust catalysts and better combustion design and control significantly reduced pollutant emissions over the past several years.

With the greatest distributed generation growth occurring in the under-5-MW market, reciprocating engines have become the fastest selling distributed generation technology in the world today. Of the reciprocating engines, spark ignition natural gas-fired units have increased their percent of market share by over 150 percent from 1995 to 1997. The reason for increased popularity stems from low initial installed costs, low operating costs, and low environmental impact.

Natural gas-fired reciprocating engine capacities typically range from 0.5–5 MW. The highest efficiencies achieved for these engines, which occur in the mid-range of 1–2 MW, are 38–40 percent for domestic engines and as high as 44 percent for some European engines.

FETC has laid the groundwork for an initiative to enhance the efficiency and environmental performance of natural gas-fired reciprocating engines to begin in 2001. A recent DOE sponsored Advanced Stationary Reciprocating, Natural Gas Engine Workshop concluded that the following goals should be pursued:

- 15-20 percent increase in efficiency
- Reduce current NO_x emission levels
- Reduce current total hydrocarbon emission levels
- Reduce current hazardous air pollutants
- Reduce the cost of electricity
- Maintain durability and reliability levels

Participation in the workshop included a consortium of four engine manufacturers and several engine component suppliers, as well as a strong university contingent, which identified potential future academic partnerships.

The impetus for continuing growth in engine use is the anticipated rapid expansion of distributed generation domestically and internationally and the preference for reciprocating engines in the less-than-5-MW market. Domestically, realizing performance goals will alleviate potential strain on natural gas supplies and essentially eliminate pollutant emission concerns. Internationally, improved cost and performance will provide U.S. engine manufacturers a strong market position.

As with the other gas-based distributed generation systems, reciprocating engines technology is adaptable to other gases such as landfill gas, propane, and gases derived from gasification of coal, biomass, and municipal, forestry, and refinery wastes.

FETC experience with reciprocating engines extends to other than natural gas-fueled systems. Under the FETC-managed Clean Coal Technology Program, a 6.4-MWe Coltec coal-fired diesel is being installed at the University of Alaska in Fairbanks.

Reciprocating engine at University of Alaska, Fairbanks

FETC in-house reciprocating engine research

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